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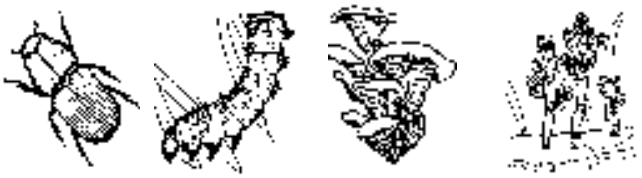

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EFFECTS OF BARE FALLOWING ON *FUSARIUM*-ASSOCIATED ROOT DISEASES AND PRODUCTION OF BARE ROOT PONDEROSA PINE SEEDLINGS AT THE USDA FOREST SERVICE LUCKY PEAK NURSERY BOISE, IDAHO

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ABSTRACT

A large-scale evaluation was conducted at the USDA Forest Service Lucky Peak Nursery near Boise, Idaho to compare bare fallowing with standard pre-plant soil fumigation with methyl bromide/chloropicrin. Comparisons were made of pre-sowing populations of potentially pathogenic *Fusarium* spp. and potentially antagonistic *Trichoderma* spp. In addition, ponderosa pine seedling emergence, density, height, diameter, and biomass production during a typical 2-year growing cycle were also compared. Soil fumigation effectively reduced soil fungal populations while fallowing a field for one growing season resulted in pathogen populations that were high enough to incite disease. Seedling emergence and 1-0 and 2-0 stand densities were significantly lower in the fallowed field; much higher disease levels were also detected in the non-fumigated field. Higher levels of healthy seedling root colonization were found in the fallowed field and pine seedlings were significantly larger in one of the fumigated fields. The major pathogen encountered in all fields was *Fusarium oxysporum.* In this evaluation, bare fallowing with periodic cultivation for 1 year prior to sowing was not an acceptable alternative to pre-plant soil fumigation with methyl bromide/chloropicrin.

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INTRODUCTION

Past production of bareroot conifer seedlings at the USDA Forest Service Lucky Peak Nursery near Boise, Idaho has relied on pre-plant soil fumigation with methyl bromide/chloropicrin formulations to kill potential pathogenic fungi and non-desirable weed seeds. Fumigation usually results in extensive decreases of soil-borne pathogens, subsequent diseases, and improved conifer seedling production (James and Beall 1999; Marshall 1983, 1985, 1986). However, costs of soil fumigation are high (> $1500/acre) and fumigants must be applied by licensed applicators and only when soil temperature and moisture are conducive for fumigant penetration (James 1989; Munnecke and Van Gundy 1974). In addition, production and use of methyl bromide is being terminated in a few years due to its implication as an important source of stratospheric ozone depletion (Evans and Greczy 1995; Shaheen 1996; Sims and others 1997). Therefore, efforts are underway to develop alternatives to pre-plant soil fumigation with methyl bromide at the Lucky Peak Nursery. Previous work indicated that the alternative fumigant dazomet (Basamid®) did not satisfactorily control soil-borne diseases at the nursery (James and Beall 1999). However, some tests (James and Beall 1999; James and others 1994b; Stone and others 1997) indicated that bare fallowing soil for at least one growing season prior to planting might result in natural decreases in pathogen populations as well as satisfactory production of conifer seedlings without soil fumigation.

We tested the effects of bare fallowing an entire production field on seedling production and compared the fallowed field with two other fields that had been operationally fumigated with methyl bromide/chloropicrin.

MATERIALS AND METHODS

Three fields (5, 10 and 14) were selected for evaluation at the nursery. Field 5 was located near the southeast portion of the nursery and consisted of soil that was slightly heavier and less well drained than the other two fields. Field 10 was located on the west side of the nursery and field 14 at the north end. During the 1997 growing season, all three fields were fallowed and periodically cultivated to reduce weed populations. In late August of 1997, fields 10 and 14 were fumigated operationally with methyl bromide/chloropicrin (66 percent methyl bromide; 33 percent chloropicrin) at a rate of 350 lbs/acre (393 kg/ha). Portions of each field were sown with the same ponderosa pine (*Pinus ponderosa* Laws.) seedlot (PP0295G053) at a rate of about 12 seeds/linear ft. in mid April 1998.

Prior to sowing, soil samples were collected from the three fields for analysis of populations of potentially pathogenic *Fusarium* spp. and associated *Trichoderma* spp. that may sometimes be disease suppressive (Papavizas 1985; Papavizas and Lumsden 1980). Experience at the nursery (James 1996; James and Beall 1999) indicated that *Fusarium* spp. (particularly *F. oxysporum* Schlecht.) were the major soil pathogens that affect conifer seedlings. Within each field, 10 soil samples were systematically collected to a depth of about 8 inches (20 cm). Samples were placed in plastic bags, kept refrigerated, and transported to the laboratory for analysis. Standard soil dilutions (Hoffman and Williams 1988; James and Gilligan 1985, 1990; Marshall 1983, 1985, 1988) were conducted. *Trichoderma* spp. were also determined on plates used to assay *Fusarium* spp., populations. Soil was initially sieved (2 mm sieve) to remove rocks, pieces of organic matter, and soil aggregates. From each sample, an approximate 5 g subsample

was oven-dried at about 100°C for at least 24 hours or until sample weight had stabilized. Oven-dry weight was then calculated to provide a standard for sample comparison. For assay of *Fusarium* and *Trichoderma* populations, 0.05 g of field-moist soil was combined with 10 ml of 0.3 percent water agar and thoroughly mixed. One ml of solution was placed on each of 3 plates of selective agar medium (Komada 1975) and spread uniformly. Plates were incubated 5-7 days at about 24°C under diurnal cycles of cool, fluorescent light. *Fusarium* and *Trichoderma* colonies were identified by their morphology on the selective medium; populations, expressed as number of colony-forming units (CFU) per g of oven-dried soil were calculated. Selected *Fusarium* isolates were transferred to carnation leaf agar (Fisher and others 1982) and potato dextrose agar for identification using the taxonomy of Nelson and others (1983).

Approximately three months after sowing, seedling assessment plots were established in the three fields. Five plots were located approximately equidistant from each other within each of two adjacent seedbeds that had been sown with the same ponderosa pine seedlot. Plots were 1.5 ft^2 (0.46 m^2) rectangles whose corners were established with large plastic pot labels; a wooden grid was placed over the corners to determine plot boundaries. Within each plot, the number of emerged, healthy-appearing seedlings was counted. Dead and dying seedlings were also counted and removed from plots for laboratory analysis of associated pathogens. Diseased seedlings were washed thoroughly to remove soil particles and their stems and main roots dissected into three equal length portions. Pieces were surfaced sterilized in a 10 percent bleach solution (0.525 percent aqueous sodium hypochlorite), rinsed in sterile distilled water, blotted dry, and placed on Komada's selective agar medium. Plates were incubated and selected *Fusarium* isolates were identified as described above. These plots were again evaluated at the end of the first growing season, approximately 6 months after sowing. Numbers of healthy-appearing and dead/diseased seedlings were determined. Selected dead seedlings were transported to the laboratory and assayed for associated pathogens. Within each plot, heights of 15 randomly selected seedlings were determined from the groundline to the top of the terminal bud.

Seedlings were grown for two years using standard nursery practices including fertilization, root pruning and undercutting. In November 1999 prior to lifting, seedling densities were determined in the approximate locations of assessment plots. Ten measurements of 1.5 ft^2 (0.46m^2) each were taken to approximate seedling densities. Within each field, 50 representative seedlings were randomly selected during lifting. These seedlings were shipped to the laboratory for analysis. Seedling roots were washed extensively to remove soil particles. Ten root tips were randomly selected for each seedling and pieces (about 5 mm) were excised from each selected tip. Root pieces were surface sterilized and incubated on the selective agar medium as described above. Abundance of *Fusarium* and three more common root-infecting fungi (*Cylindrocarpon, Trichoderma, and Penicillium* spp.) on root pieces was determined. Seedling heights (nearest cm) were measured from the groundline (cotyledon scar) to the tip of the main terminal bud. Seedling diameters were also measured to the nearest mm. Biomass of individual seedlings, including all root and shoot tissues, was estimated by determining oven-dry (100°C for at least 24 hours.) weight (g).

Data on seedling emergence, 1-0 and 2-0 density, first-year mortality, root colonization of 2-0 seedlings, and height, diameter, and biomass of 2-0 seedlings were analyzed with a one-way analysis of variance. Statistically different (P=0.05) means were located using Tukey's HSD.

RESULTS

Methyl bromide/chloropicrin fumigation nearly eliminated *Fusarium* populations in both fields 10 and 14 (table 1); only one sample in field 14 yielded *Fusarium*. However, in the fallowed, non-fumigated field, *Fusarium* spp. were common, averaging about 750 cfu/g for the 10 samples. Three samples exceeded the threshold of 1000 cfu/g considered as high enough to incite important levels of disease in conifer seedlings (Hildebrand and Dinkle 1988; James and others 1990, 1996). Although *Trichoderma* spp. were common in all three fields, they were especially abundant in the fumigated fields by the time of sowing in the spring following fumigation (table 1). Ratios of *Trichoderma* to *Fusarium* (T/R ratios) are used to roughly approximate soil suppressiveness to *Fusarium*-associated diseases (James and Beall 1999; James and others 1996). The higher the ratio, the more the soil is potentially disease-suppressive. Ratios varied widely in field 5 (table 1), indicating that *Fusarium* and *Trichoderma* spp. were not uniformly distributed in soil.

Seedling emergence, density, first-year mortality and height are summarized in table 2. Significantly fewer seedlings emerged in the non-fumigated field and seedling densities at the end of both the first and second growing seasons were less in this field. First-year seedling mortality was significantly greater in the non-fumigated field than either of the two fumigated fields. First-year heights of surviving seedlings were not significantly greater in fumigated fields, although seedling heights in field 10 were less than expected.

Table 1. Effects of bare fallowing and methyl bromide/chloropicrin soil fumigation on pre-sowing soil populations of *Fusarium* and *Trichoderm*a spp. at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho[1].

	Fusarium			*Trichoderma*			T/F Ratio[2]		
	Fields			Fields			Fields		
Sample	5	10	14	5	10	14	5	10	14
1	868	0	0	1468	8301	7477	1.7	-	-
2	1044	0	0	1113	8301	5901	1.1	-	-
3	138	0	0	1314	7477	6268	9.5	-	-
4	415	0	0	900	8171	6591	2.2	-	-
5	349	0	69	978	8301	8301	2.8	-	120.3
6	1608	0	0	909	8301	8301	0.6	-	-
7	826	0	0	620	8102	8301	0.7	-	-
8	685	0	0	754	8301	8301	1.1	-	-
9	137	0	0	2049	8171	8301	15.0	-	-
10	1475	0	0	1615	7965	8301	1.1	-	-
Ave.	754.5	0	6.9	1172.0	8139.1	7604.3	3.6	-	-
STD	489.4	0	20.7	416.7	258.9	929.6	4.5	-	-

[1]Based on 10 systematically located soil samples throughout treated fields; fungal populations given as cfu/g oven-dried soil; STD = standard deviation. Field 5 was bare fallowed with periodic cultivation for one year prior to sowing; fields 10 and 14 were fumigated with methyl bromide/chloropicrin in the late summer prior to sowing the following spring.

[2]The ratio of *Trichoderma* to *Fusarium* populations; if either fungus was not detected, no ratio was calculated.

Dead and dying first-year seedlings were extensively colonized with *Fusarium* spp. (table 3). Assays indicated that, in some cases, *Fusarium* had not completely colonized all stem and root tissues by 3 months, but completed colonization by 6 months. In most cases, seedlings were initially attacked at or just below the groundline followed by colonization of roots below and stems above this infection point. As with previous root disease evaluations at the Lucky Peak Nursery (James 1996; James and Beall 1999), little or no seedling mortality was detected during the second growing season, even in the non-fumigated field.

Fusarium spp. colonized roots of healthy-appearing 2-0 seedlings in the non-fumigated field at significantly higher levels than in fumigated fields (table 4). More than 90 percent of the sampled root pieces were colonized by *Fusarium* spp. in the non-fumigated field, while less than 20 percent of the pieces were colonized in the fumigated fields. *Cylindrocarpon* spp., common rhizosphere inhabitants who are sometimes pathogenic (James and others 1994a) were isolated at relatively low levels from seedling roots, except from some seedlings in field 14 (table 4). As expected from soil population assays (table 1), *Trichoderma* spp. were recovered from seedling roots at much higher levels in the fumigated fields. *Penicillium* spp. were isolated at low frequencies from seedlings grown in all three fields.

Table 2. Effects of bare fallowing and methyl bromide/chloropicrin soil fumigation on seedling emergence, 1-0 and 2-0 seedling densities, first-year seedling mortality and 1-0 seedling height of bareroot ponderosa pine at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho[1].

Measurement	Field 5	Field 10	Field 14
Emergence[2]	19.4 A	29.9 B	27.4 B
STD	4.4	4.7	4.6
1-0 Density[3]	16.0 A	29.7 B	28.4 B
STD	3.9	4.2	6.0
2-0 Density[3]	17.2 A	24.9 B	23.1 B
STD	3.5	2.8	4.7
1st-Year Mortality[4]	8.1 A	2.0 B	4.3B
STD	2.7	1.1	1.6
1-0 Height[5]	7.2 AB	6.7 B	9.5 A
STD	1.7	1.6	2.0

[1]Based on seedlings within 10 plots (1.5 ft^2 = 0.46m^2) systematically located within fields. STD = standard deviation. Within rows, means followed by the same capital letter are not significantly different (P=0.05) using Tukey's HSD.

[2]Emergence as average number of seedlings per 1.5 ft^2 (0.46m^2) approximately 3 months after sowing.

[3]Average number of seedlings per 1.5 ft^2 (0.46m^2).

[4]First-year mortality was a composite of the average number of dead seedlings per 1.5 ft^2 (0.46m^2) found at 3 and 6 months after sowing; noticeable mortality did not occur during the second growing season.

[5]Based on randomly sampling 15 first-year seedlings per 1.5ft^2 (0.46m^2).

Average seedling height, diameter and biomass were significantly greater in field 14 than in either the other fumigated or non-fumigated fields (table 5). Seedlings produced in all three fields averaged above regional standards for acceptable seedlings. Minimum acceptable height and diameter for 2-0 ponderosa pine seedlings are 10.2 cm and 4.0 mm, respectively. Therefore, although there were fewer seedlings produced per unit area in the non-fumigated field, those that survived were approximately the same size as those produced in field 10 that had been fumigated. Although seedlings produced in both fumigated fields had similar densities (table 2), those from field 14 where much larger (table 5). Other factors, such as non-assayed pathogens (particularly water mold fungi such as *Phytophthora* and *Pythium* spp.) or soil structural differences may have adversely affected seedling growth in field 10.

Table 3. *Fusarium* colonization of dead 3-month and 6-month old ponderosa pine seedlings at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho.

Seedling Age	Field 5	Field 10	Field 14
3 Months			
No. Sampled	24	6	20
Percent Inf.[1]	100	83	100
Colon. Rate[2]	90.3	77.8	91.7
6 Months			
No. Sampled	7	5	6
Percent Inf.[1]	100	100	100
Colon. Rate[3]	100	100	100

[1]Percent of sampled seedlings infected with *Fusarium* spp.

[2]Percent of root and stem pieces (3 pieces sampled per seedling) colonized with *Fusarium* spp.

[3]Percent of root and stem pieces (4-10 pieces sampled per seedling) colonized with *Fusarium* spp.

Table 4. Effects of bare fallowing and methyl bromide/chloropicrin soil fumigation on root colonization of healthy-appearing 2-0 bareroot ponderosa pine seedlings by selected fungi at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho[1].

	Fusarium		*Cylindrocarpon*		*Trichoderma*		*Penicillium*	
Field[2]	No.	STD	No.	STD	No.	STD	No.	STD
5	9.4 A	0.8	1.7 A	1.4	1.3 A	1.5	0.4 A	0.6
10	1.9 B	1.3	1.1 A	1.3	8.7 B	1.1	0.3 A	0.8
14	1.8 B	1.4	4.0 B	2.0	7.8 B	1.5	0 A	0

[1]Based on sampling 50 healthy-appearing seedlings collected from each field at the time of lifting. No. = average number of root pieces (10 sampled per seedling) colonized by particular fungi; STD = standard deviation. Within columns, means followed by the same capital letter are not significantly different (P=0.05) using Tukey's HSD.

[2]Field 5 was bare fallowed with periodic cultivation for one year prior to sowing; fields 10 and 14 were fumigated with methyl bromide/chloropicrin in the late summer prior to sowing the following spring.

Table 5. Effects of bare fallowing and methyl bromide/chloropicrin soil fumigation on height, diameter and biomass production of 2-0 bareroot ponderosa pine seedlings at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho[1].

	Height (cm)		Diameter (mm)		Biomass (g)	
Field[2]	Ave.	STD	Ave.	STD	Ave.	STD
5	17.4 A	3.5	4.95 A	0.97	26.6 A	11.2
10	17.9 A	2.9	5.06 A	1.17	26.7 A	11.2
14	26.8 B	3.8	6.22 B	1.24	35.2 B	12.8

[1]Based on sampling 50 healthy-appearing seedlings collected from each field at the time of lifting. STD = standard deviation. Within columns, means followed by the same capital letter are not significantly different (P=0.05) using Tukey's HSD.

[2]Field 5 was bare fallowed with periodic cultivation for one year prior to sowing; fields 10 and 14 were fumigated with methyl bromide/chloropicrin in the late summer prior to sowing the following spring.

Assays from soil, diseased seedlings, and roots of healthy-appearing seedlings indicated that *F. oxysporum* was by far the most common *Fusarium* species isolated (table 6). *Fusarium* spp. found much less frequently included *F. sporotrichioides* Sherb., *F. solani* (Mart.) Appel & Wollenw., *F. acuminatum* Ell. & Ev. and *F. proliferatum* (Mitushima) Nirenberg

DISCUSSION

Routine application of pre-plant soil fumigation in bareroot forest nurseries has allowed growers to consistently produce high-quality seedlings with few weed and soil-borne pathogen problems (James 1989; Smith and Bega 1966). General biocides, such as methyl bromide/chloropicrin mixtures, kill nearly all soil microorganisms, including important pathogens such as *Fusarium* spp. (Miller and Norris 1970; Munnecke and Van Gundy 1979; Munnecke and others 1978). When pathogens are eliminated or greatly reduced by soil fumigation, potential disease is low unless pathogens are inadvertently re-introduced into fumigated fields on soil, machinery, or seed (Marois and others 1983; Smith and Bega 1966). Potentially disease suppressive fungi such as *Trichoderma* spp. are often rapid colonizers of fumigated soil (Banerjee and Anderson 1992; Danielson and Davey 1969). If sufficient antagonists occur in soil chances for pathogen establishment at high enough levels to incite extensive disease are minimal (Papavizas 1985; Papavizas and Lumsden 1980).

Pre-plant soil fumigation with methyl bromide/chloropicrin has routinely occurred at the Lucky Peak Nursery for many years (Hoffman and Williams 1988; Marshall 1983, 1985, 1986), resulting in consistent production of high-quality seedlings. However, because methyl bromide will no longer be available for use in the United States in the near future (Evans and Greczy 1995; Shaheen 1996), alternatives must be developed. Previous work (James and Beall 1989) indicated that an alternative chemical fumigant (dazomet) was not nearly as effective as methyl bromide. However, limited tests (James and others 1994b; Stone and others 1997) found that fallowing soil for at least one year prior to sowing with periodic cultivation may be an acceptable alternative. Unfortunately, results from our current evaluation of bare fallowing on larger, field-size scales were disappointing. Although seedlings of acceptable quality were produced in the fallowed field, there were fewer of them produced per unit area than in two fumigated fields. Much higher disease caused by soil-borne *Fusarium* was detected in the non-fumigated field because relative high pathogen populations persisted after fallowing.

Table 6. *Fusarium* species isolated from soil and roots of diseased first-year and healthy-appearing 2-0 ponderosa pine seedlings at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho[1].

Percent of Isolates			
Fusarium species	Soil Samples	Diseased Seedlings	2-0 Seedlings
F. oxysporum	97.3	97.7	95.7
F. sporotrichioides	0.9	1.3	1.1
F. solani	0.9	0	0.9
F. acuminatum	0.9	1.0	0
F. proliferatum	0	0	2.3

[1]Soil samples collected prior to sowing; diseased seedlings collected 3 and 6 months after sowing during the first growing season; 2-0 seedlings collected at the end of the second growing season.

Soil characteristics differed in the three evaluated fields. For example, in the non-fumigated field, soils were heavier, contained high levels of clay, and generally poorly-drained. Portions of field 10 were also poorly drained, which may help explain the smaller seedlings produced in this field. In our test, the most-productive field was 14 where consistently large, high-quality seedlings were produced after fumigation. It would be interesting to compare fumigation and fallowing on seedling production within this one field.

Randomized replicated plots with different treatments were not installed within the three fields. Because one treatment (fumigation or fallowing) occurred in an entire field, assessment plot replications for statistical purposes were really "pseudo-replications". Therefore, results must be interpreted cautiously. If non-fumigated and fumigated plots were located adjacent to each other in the same field as in a previous evaluation (Stone and others 1997), results may have been different. Also, more satisfactory seedling production might be achieved in fields fallowed for more than one year before sowing a conifer crop. Fallowing and rotating fields might be a viable option, particularly if reduced seedling demand allows several fields to be out of production each year. Another way of possibly enhancing efficacy of fallowing is by introducing biological control agents during sowing (Alabouvette and others 1993; Harman and others 1989; Papavizas 1985; Papavizas and Lumsden 1980). This may improve seedling protection during their first growing season when they are most vulnerable to pathogens (Bloomberg 1971, 1981). Tests are currently underway at the Lucky Peak Nursery to evaluate one biocontrol agent (*Trichoderma harzianum* Rifai) and soil solarization as possible alternatives to methyl bromide/chloropicrin soil fumigation.

The major soil-borne pathogen at the Lucky Peak Nursery requiring control is *F. oxysporum*. This species is readily isolated from soil, where it colonizes organic matter (Gordon and Martyn 1997; James and others 1991). The fungus remains viable between susceptible plant crops as resistant chlamydospores (Bloomberg 1976; Gordon and Martyn 1997) and sometimes as sclerotia (James and others 1991; Nelson and others 1983). However, without susceptible hosts, propagules of *F. oxysporum* tend to decline naturally in soil, primarily due to antibiosis from other microorganisms (Bloomberg 1976; James and others 1991). Natural inoculum reduction can be enhanced by periodic soil cultivation (Stone and others 1997).

Fusarium oxysporum readily colonizes conifer seedling roots, particularly cortical tissues (Bloomberg 1973, 1981; James and

others 1991). However, root colonization only sometimes results in disease. For disease to occur, host tissues must be extensively colonized by pathogenic fungal strains and environmental conditions must be conducive for disease (Bhatti and Kraft 1992; Gordon and Okamoto 1992; James and others 1991). Pathogenic and non-pathogenic isolates of *F. oxysporum* appear morphologically similar (Bloomberg 1971, 1976; Burgess and others 1989; James and others 1991). Therefore, isolation of the fungus from soil or plant tissues is not sufficient to determine disease potential. However, recent molecular techniques may improve delineation of pathogenic strains without requiring extensive pathogenicity tests (Appel and Gordon 1995; Assigbetse and others 1994; Bentley and others 1995; Gordon and Okamoto 1992).

Roots of seedlings without disease symptoms produced in the non-fumigated field were extensively colonized by *F. oxysporum*. However, infected seedlings met regional size guidelines for successful outplanting. Previous work (Dumroese and others 1993; Smith 1967) indicated that seedlings with extensive *Fusarium* root colonization usually perform satisfactorily following outplanting. In addition, *Fusarium* spp. tend to decrease on roots over time and are replaced by other microorganisms, particularly mycorrhizal fungi (Smith 1967).

Our evaluation indicated that bare fallowing some fields at the Lucky Peak Nursery may not satisfactorily replace pre-plant soil fumigation with methyl bromide/ chloropicrin. These fields may require additional treatments such as adding biological control agents or fumigating with other chemicals to reduce pathogen levels. Since dazomet was previously unsatisfactory in some nursery fields (Hoffman and Williams 1988; James and Beall 1999), other chemical fumigants, e.g., chloropicrin, metam-sodium, and methyl iodide should be evaluated (Sims and others 1997).

Many bareroot nurseries traditionally use cover crops to prevent soil erosion and maintain soil tilth between crops of conifer seedling (Hansen and others 1990; James and others 1996). Cover crops are often incorporated into soil a few months prior to sowing conifer crops. Unfortunately, this often results in high populations of *F. oxysporum*, which uses incorporated organic matter as food sources (Hansen and others 1990; James and others 1996). Increased soil levels of *F. oxysporum* adversely affects seedling production (Hansen and others 1990; James and others 1996; Stone and others 1997). However, some cover crops may offer advantages over others from the standpoint of effects on disease potential. For example, species of *Brassica* have successfully been used to reduce soil pathogen populations because they produce isothiocyanates, which are toxic to many microorganisms, when decomposing in soil (Angus and others 1994; Clapp and others 1959). Some *Brassica* cultivars produce very high levels of these toxins, which are the same chemicals released from some synthetic fumigants (Barnard and others 1994; Davis 1988; Kelpsas and Campbell 1994). *Brassica* cultivars should be evaluated at the Lucky Peak Nursery as a supplement to fallowing for control of soil-borne pathogens. By combining field rotation, periodic cultivation, and fallowing with biological control amendments and incorporating *Brassica* green manure crops, satisfactory alternatives to methyl bromide/chloropicrin soil fumigation may be found.

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